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SOLID STATE RF SOURCES

1.0 INTRODUCTION

The following notes discuss the state of the art of solid state RF sources in terms of power output and cost for several frequency bands from 225 MHz to 36 KHz. It is emphasized that the cost of current devices is influenced by many factors, including production quantities, frequency stability, noise characteristics, tuning requirements and power output. Some of these factors and their relation to current design and future needs for the ARPA systems are discussed in Section 2 below. A detailed bibliography is included for the convenience of those who may wish to investigate this subject in more detail.

2.0 SOME GENERAL CONSIDERATIONS IN RF SOURCE DESIGN AND ECONOMICS

2.1 Cost Factors

The power output requirement is an obvious cost factor but not so obvious is the frequency stability and noise requirements that strongly influence the source design. For example, the 6 gHz low power microwave source that sells in quantity for less than 500 may, at first, appear a poor economic choice compared to the reflex klystron it replaced which could be purchased for about $50. However, when one considers the power supply and automatic frequency control requirements needed for the klystron the solid state source typically is more economical. The power supply requirements are typically 24 VDC which is often obtained directly from float charged batteries and the frequency control is continued within the solid state source by means of a phase locked loop which synchornizes the microwave oscillator to the harmonic of a lower frequency crystal oscillator.

For the system being considered simplification may be possible. In particular, digital modulation systems can tollerate considerably higher level or phase noise than most analog systems for which most current RF sources are designed. This could lead to simpler and more economical devices. Further, it should be recognized that avalanche transit-time and transferred electron device technology is yet quite young and hence considerable improvement in the cost

vs power output relationship can be expected.

The cost is almost certain to remain closely related to the power output requirement and this requirement has not yet been defined for a particular model for the ARPA network. Quite low powers can provide reliable high data rate transmission over long line-of-sight paths if directional antennas are used. However, power output requirements will be moderate for omni-directional systems and this has influenced the status of current technology. As will be noted below, RF sources with output capability in the 10 to 100 watt range exist for P band (225 - 400 MHz). This is achieved by techniques of combining the outputs of 2 or more amplifiers through hybrids. Such sources are typically used in various mobile applications which employ omni antennas and often suffer severe obstruction loss.

Power combining techniques are also applicable to microwave sources but are generally not applied because the resulting complexity would make the device both costly and unreliable compared to alternative devices such as TWT amplifiers for the 1 to 100 watt power range and multicavity klystrons for higher powers. Both these devices have high power gains (30 to 50 db) hence where power requirements exceed one or two watts at frequencies above 2 GHz such electron devices are typically still applied.

2.2 Peak Power Capabilities

Most if not all solid state microwave devices have relatively low thermal time constants and very definite peak voltage limitations. Therefore, the devices are peak power limited hence we cannot substantially increase peak power by lowering the duty cycle. This is likely of little importance in designing repeaters and high capacity stations since they must be designed to be transmitting a substantial period of the time. However, for low capacity portable stations it would be desirable to employ devices that operate efficiently with high peak power and low duty cycle. Even if RF power devices are employed that are peak power limited it is desirable that the devices may be turned off and on rapidly to minimize power consumption of the portable terminal. This requirement might influence not only the choice of microwave source but may also influence the choice or modulation technique.

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3.0 CHARACTERISTICS OF AVAILABLE RF SOURCES

Cost and performance characteristics of available UHF and microwave RF sources for several microwave frequency bands from 225 MHz through 36 GHz are summarized below. The characteristics listed are believed to represent the state of the art for sources that are currently production devices for commercial and military systems since this is of most interest for the application being evaluated since cost will be a major consideration.

3.1 Sources for P-Band (225 - 400 MHz)

Transistors are exclusively used to generate up to 150 watts of CW power in this frequency band. The power train takes the form of a low level oscillator followed with series amplifier stages up to 50 watts then parallel power stages to reach the 100-150 watt level. The parallel output stages use hybrid power combiners to sum the individual stage powers. These power sources are widely used in military systems and commonly the amplifiers operate over the entire 225-400 MHz band with no tuning. Transmitters are common at 1 watt, 10 watt, and 100 watt outputs depending upon the application.

Modulation is usually applied at the low level source input - typical modulations used are AM, FM, PM, and multitone. The limiting characteristic of transmitters using such power trains is amplifier distortion and thermal properties. At the higher power levels, 50 watts and above, a forced cooling system is required to keep transistor junction temperatures within acceptable reliability range.

Typical available sources in this band have the following characteristics:

Frequency:	225-400 mHz, broadband
Power Output:	Up to 100 watts
Efficiency:	30%
Volume:	10 watts - 6 in^3
	100 watts - 20 in^3 (not including cooling hdwe)
Weight:	10 watts - 6 oz
	100 watt - 20 oz
Cost:	10 watts - $600
	100 Watts - $2100

Future trends are toward higher power transistors designed for improved impedance matching, lower distortion and lower thermal resistance. This will result in lower hardware costs by reducing the number of parallel stages required to obtain 100 watt levels. Packaging trends are toward hybrid construction providing low volume and weight.

3.2 Microwave Sources

3.2.1 General

There are today five major classes of solid-state devices for generating microwave power: microwave transistors, transistor-driven varactor harmonic-generator chains, tunnel diodes, avalanche transit-time devices, and transferred electron devices. The advantages and disadvantages of using any one of these devices for power generation depend on the desired frequency, output power, noise performance, cost and size.

The following is a summary of the state-of-the-art performance of the different solid-state microwave power sources available now in the various frequency bands. Future trends will be also discussed.

In order to simplify the characterization of the many available sources, each frequency band is discussed separately.

3.2.2 L-Band Sources (400-1700 MHz)

Microwave transistors are widely used in this band. Power output varies from a few milliwatts to 20 watts. The best available power transistor sources are capable of about 15W CW at L-band, or 100W pulse power. Efficiencies reach 60% at 1 GHz (50% at 2 GHz). Input voltage requirement is normally 28 VDC. Size and weight vary with output power. Typical available source in this band has the following characteristics.

(A) HIGH POWER		(B) LOW POWER	
Frequency:	1 GHz	Frequency:	1 GHz
Power Output:	2 watts	Power Output:	50 MW
Efficiency:	20%	Efficiency:	1.5%
Volume:	15 In^3	Volume:	2 In^3

(A) HIGH POWER		(B) LOW POWER	
Weight:	25 oz.	Weight:	2 oz.
Price:	<$1,500	Price:	$300
Tuning:	Voltage Tuning	Tuning:	Voltage Tuning

Transistor performance advances seem to have leveled. But high volume technology gained in manufacturing digital circuits can be applied to L-band transistors, bringing their cost down significantly.

3.2.3 S-Band Sources (1.7-3.7 GHz)

Several solid state microwave devices are used in this band, namely, microwave transistors, transistor driven varactor harmonic-generator chaine, bulk effect devices in LSA modes, and avalanche devices in both Trapatt and Impatt modes. Power output, efficiency, size and price vary depending on the device used. Maximum attainable power in this band is 10W CW using microwave transistors and 20W using transistor multiplier chain. The following is typical available characteristics in the S-band.

(A) HIGH POWER		(B) LOW POWER	
Frequency:	2 GHz	Frequency:	2.0 GHz
Power Output:	2 watts	Power Output:	40 MW
Efficiency:	15%	Efficiency:	2%
Size:	170 In^3	Size:	2 In^3
Weight:	?	Weight:	3 oz.
Price:	<$12,000	Price:	$350
Tuning:	Both electrical and mechanical	Tuning:	Voltage tuning

3.2.4 C-Band Sources (3.7-6.4 GHz)

In this band, there are wide selections of microwave sources ranging in power from a few milliwatts to a maximum of 4 watts CW at the high end of the band. Various devices are used in this band depending on frequency, power output and size. Microwave transistors are used at the low end, transistor multiplier chain is used at mid and high end of the band, and bulk and avalanche devices are used at the high end of the band. Typical source in this band has the following characteristics:

(A) HIGH POWER		(B) LOW POWER	
Frequency:	6 GHz	Frequency:	5.5 GHz
Power Output:	1.5 watt	Power Output:	100 MW
Efficiency:	10%	Efficiency:	4%
Size:	125 cubic in.	Size:	1 In^3
Weight:	?	Weight:	1.5 oz
Price:	<$12,000	Price:	<$500
Tuning:	Voltage	Tuning:	Mechanical

3.2.5 X-Band Sources (6.4-10.9 GHz)

Sources using both bulk and avalanche devices are used in this band. Maximum power attainable is 4 watts in the low end of the band and 2 watts at the high end of the band. However, higher power is becoming available with new circuit techniques. Typical source in this band has the following characteristics:

(A) HIGH POWER		(B) LOW POWER	
Frequency:	10.9 GHz	Frequency:	8.0 GHz
Power Output:	1 watt	Power Output:	50 MW
Efficiency:	8%	Efficiency:	1%
Size:	25 In^3	Size:	>1 In^3
Weight:	20 oz.	Weight:	4.0 oz.
Price:	<$2,000	Price:	<$500
Tuning:	Varactor Tuning	Tuning:	Mechanical

3.2.5 K-Band Sources (10.9-36 GHz)

Maximum attainable CW power in this band is 2 watts at the low end and a few hundreds of milliwatts at the high end of the band. Tunnel diodes and both bulk and avalanche devices are used in this band. Sources with higher power are currently being build in the laboratory. However, they are not commercially available but may be practical in the next year or two. Typical source has the following characteristics:

Frequency:	26 GHz
Power Output:	100 MW
Efficiency:	0.5%
Volume:	9 In^3
Weight:	8 oz.
Price:	<$700
Tuning:	Mechanical

4.0 EXAMPLE OF DESIGN OF SIMPLE SOLID STATE SOURCE DESIGN

A microwave power source is essentially a device which converts dc power to microwave energy. A typical source in its simplest form consists of an active device which when biased correctly displays a negative resistance, a resonant cavity, an output coupling probe, and a tuning device. Figure 1 shows a schematic of a typical microwave source.

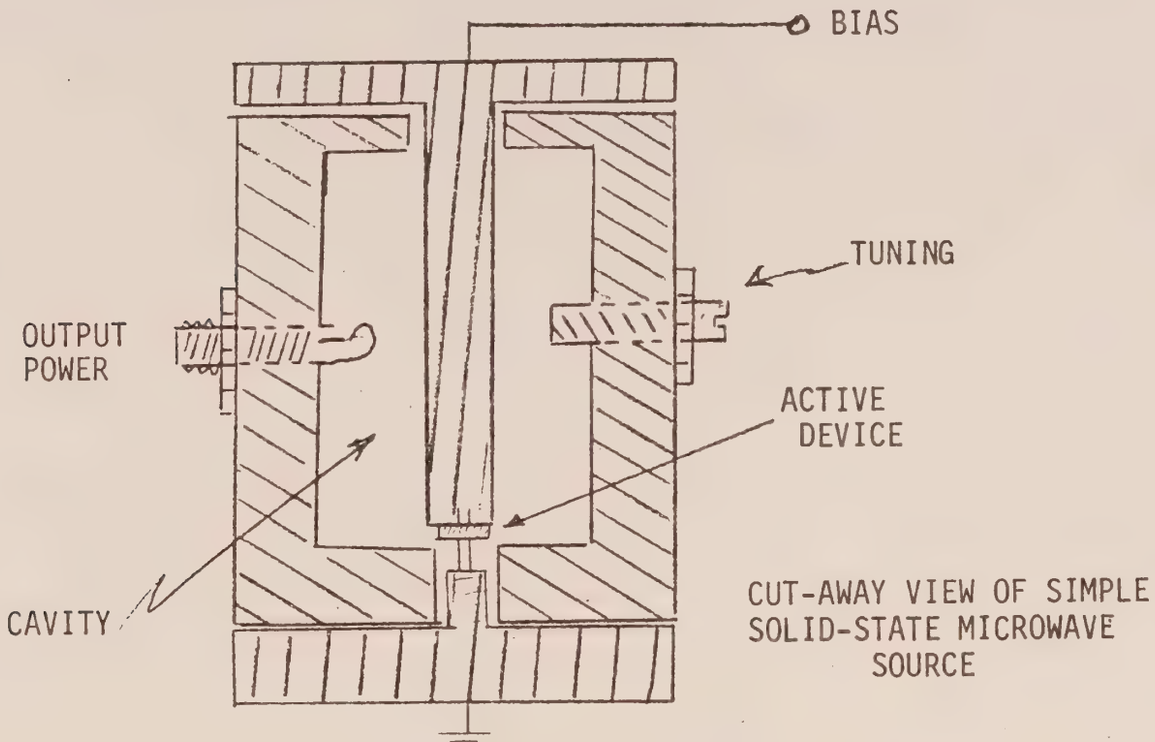

FIGURE 1

Tuning could be either mechanical or electrical. In the case of mechanical tuning, a simple capacitive stub is used to vary the resonance frequency of the cavity. In the case of electrical tuning on the other hand, a varactor diode is used in place of the stub. Thus by varying the diode capacitance with an external dc voltage the resonance frequency of the cavity will be changed.

The price and size of a microwave source depend largely on the requirements. For example, if high power output is the objective, an array of active devices must be used in a sophisticated circuit configuration and adequate heat sinking must be provided. If frequency stability is of importance, a phase locking circuitry must be used. Figure 2 shows a block diagram of a phase locked microwave source.

The option of using any of the presently available microwave active devices depends on the requirement of power output, frequency, noise performance and various other parameters. If, for instance, AM or FM noise is not of primary importance, one can use an avalanche diode as a source of microwave energy. Consequently, many factors and added circuit complexity enter into the design of a microwave energy generator depending on the application.

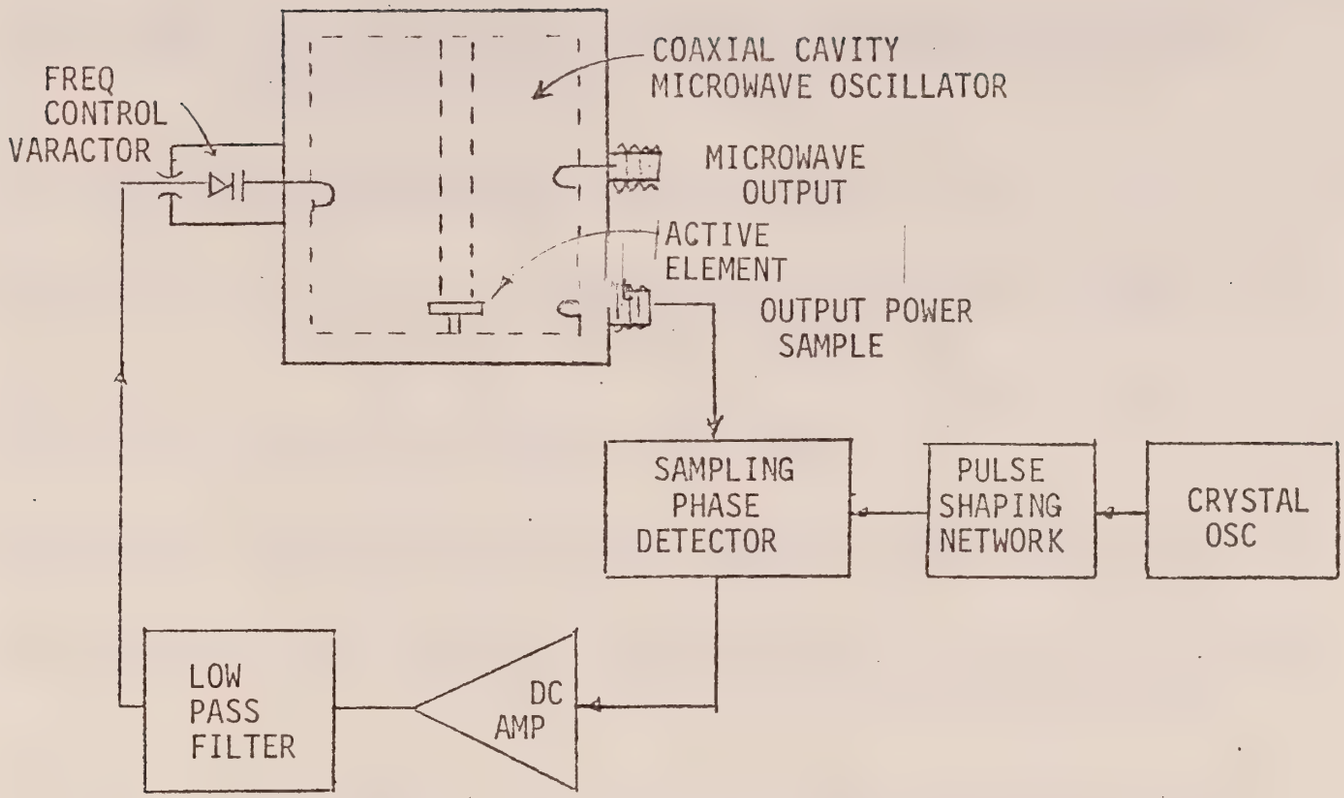

FIGURE 2: BLOCK DIAGRAM OF
PHASE LOCKED MICROWAVE SOURCE.

SOLID STATE MICROWAVE
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